POTENTIAL IMPACTS OF CLIMATIC CHANGE ON THE SOUTHERN OCEAN ECOSYSTEM

R.G. CHITTLEBOROUGH

Chittleborough, R.G. 1991 07 01: Potential impacts of climatic change on the Southern ocean ecosystem. *Memoirs of the Queensland Museum* 30(2):243–247. Brisbane. ISSN 0079-8835.

Global climate change has the potential to disrupt the delicately poised thermal balance in surface waters of the Southern Ocean around Antarctica, threatening this highly productive ecosystem with severe and permanent collapse. Pivotal in this process is a diminution of the important (but little studied) CO_2 sink in the Southern Ocean, resulting in a series of feedback loops accelerating global warming and intensifying impacts upon the Southern Ocean ecosystem.

As well as outlining the processes involved and stressing the urgent need for further research, this paper underlines our wider social responsibilities to press for fresh policies essential to arrest the global changes before irreversible harm is done to the Antarctic environment and ecosystems, with their global consequences to our life support system.

R.G. Chittleborough, 24 Watt St., Swanbourne, Western Australia 6010; 4 January 1991.

The Convention for Conservation of Antarctic Marine Living Resources, (CCAMLR), while "RECOGNISING the importance of safeguarding the environment and protecting the integrity of the ecosystem of the seas surrounding Antarctica"; places its main emphasis on the impacts which harvesting may have, not only upon target species but also upon ecological relationships. Article II of the Convention also commits us to the conservation principle of "prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades..."

However, even if there was no exploitation of living (or mineral) resources in the Antarctic, the environment and ecosystems there are now threatened by accelerating climatic changes being triggered globally by mankind.

Not surprisingly, the main focus of attention presently being given to global climatic change is how the changes will impact on ourselves. We have begun to consider how quickly we may have to adapt in terms of water supply, agriculture, forestry, transport, coastal developments, etc. Far less attention is being given to potential impacts upon natural ecosystems, particularly the more remote Antarctic ecosystem.

PROCESSES MAINTAINING THE SOUTHERN OCEAN ECOSYSTEM

The main driving force of this system is the annual pulse of winter sea ice extending northwards from Antarctica to cover some 20 million square kilometres of the Southern Ocean, retreating each summer almost to the mainland coast. This annual pulse drives the vertical circulation of these waters (Fig. 1), cold brine released by the formation of sea ice sinking along the continental shelf, with compensatory upwelling of nutrient rich water farther offshore at the Antarctic Divergence (Sverdrup *et al.*,1942). Microalgae growing from the base of the sea ice, and phytoplankton blooms each spring and summer within the nutrient rich Antarctic Surface Water, are the main basis of the high productivity of the Southern Ocean ecosystem (Chittleborough, 1984). Estimates of gross annual production of phytoplankton are 6.1-38 billion tonnes. This represents an annual uptake of 1.5–10 billion tonnes of CO_2. Part of that CO_2 is released again during metabolic activity of consumers, but a proportion sinks as detrital organic carbon into Antarctic Bottom Water.

Some dissolved CO_2 from the atmosphere is also carried down in both the Antarctic Bottom Water and the Antarctic Intermediate Water sinking at the Antarctic Covergence.

While it is widely accepted that the Southern Ocean is a major sink for CO_2 measurements of the sink are not available. Takahashi (1987) estimated that the Southern Ocean removes 6.67 billion tonnes of CO_2 per year from the atmosphere or 70% of total uptake flux of all oceans.

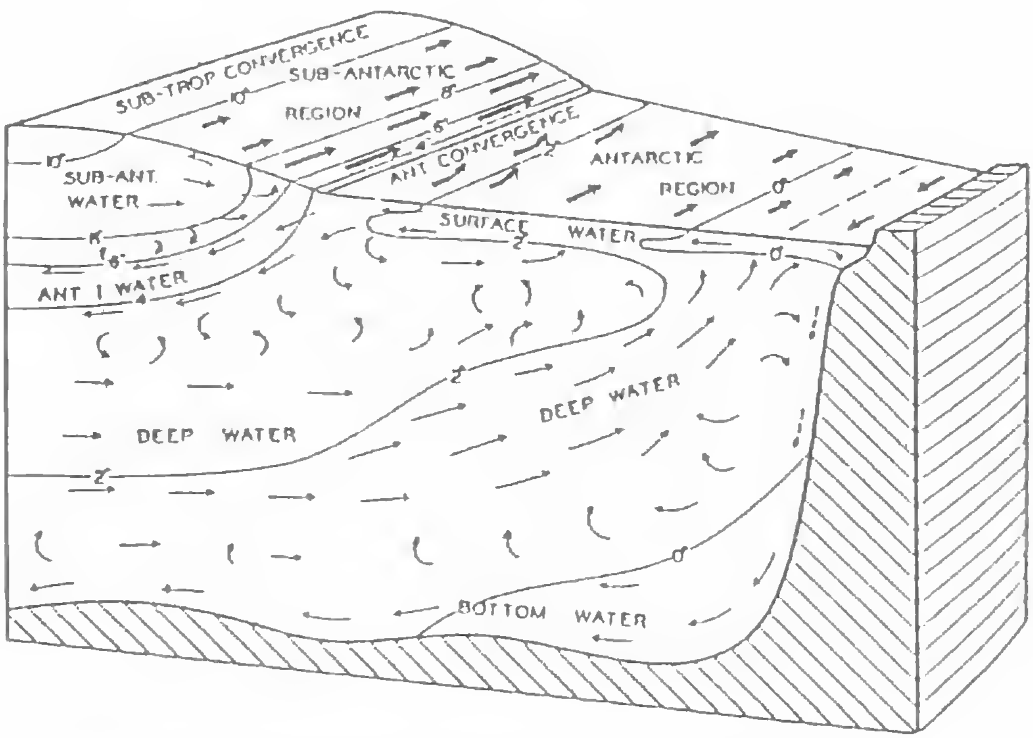

Fig. 1. Representation of currents and water masses of the Antarctic regions (after Sverdrup et al., 1942).

THERMAL STABILITY

The advent of satellite sensing affords a practical means of assessing long term variations in thermal stability of the Southern Ocean. Jacka (1983) stressed the importance of monitoring the extent of winter sea ice, as this parameter is likely to be one of the earliest indicators of any significant climatic change.

As satellite images of the winter sea ice around Antarctica became available, extensive open waters within the ice (polynyas) were discovered. The largest of these, the "Weddell Polynya" (actually situated to the east of the Weddell Sea) measured 1100 x 650 km in September 1975. The Weddell Polynya appeared in three consecutive winters, 1974–1976, then disappeared until 1980 (Comiso and Gordon, 1987). Farther east at c. 45°E, the Cosmonaut Polynya appeared in 1973,1975, 1979,1982 and 1986. While it is not suggested that these polynyas were caused by the greenhouse effect, they do serve to illustrate the delicate balance in the formation and maintenance of sea ice.

Rather more information is available on the extent and distribution of residual sea ice during summer, as this is the time of greatest shipping activity in the Southern Ocean. While much of this information is still to be collated, an analysis by Bentley (1984) indicates that the extent of the Antarctic sea ice in summer decreased by 2.5 million square kilometres between 1973 and 1980, and perhaps by more since the 1930's.

There is evidence of a recent increase in air temperature over the Southern Ocean. Budd (1980) recorded an increase in mean annual air temperature at subantarctic islands of 0.4° C during 1958–1978 and by 0.6° C at stations on the edge of the Antarctic continent. At Kerguelen Island, situated on the northern edge of Antarctic Surface Water, the mean annual air temperature has risen during 1964–1982 by 2.1° C (Jacka, Christou & Cook, 1986), the increase being more marked in summer than in winter. Similar rises in mean annual air temperature are recorded for Amsterdam Island and Marion Island.

On glaciated subantarctic islands such as Heard Island, glacial retreat has accelerated dramatically in recent decades (Allison and Keage, 1986). Heard Island, located towards the outer margin of Antarctic Surface Water, and its glaciers moving rapidly on steep slopes (short residence time of the ice), affords sensitive indicators of changes in climate.

While there is a paucity of hard data on variability within the Southern Ocean region, it is evident from the great changes occurring seasonally and in the longer term, that the thermal balance of this region is delicately poised.

POTENTIAL FOR CHANGE

Global climate models used to predict surface air temperature changes due to increasing atmospheric CO_2, generally indicate greater increases in temperature at higher latitudes. For example, Rind (1984) indicated that a doubling of atmospheric CO_2 would raise mean annual air temperatures over most of Australia by 4+°C, while over the Southern Ocean around Antarctica increases of 6–8°C could be anticipated. Sea surface temperatures in the Southern Ocean can therefore be expected to rise by a greater amount than in lower latitudes.

The most immediate effect of Southern Ocean surface isotherms contracting southwards would be to further restrict the distribution of cold tolerant species living within Antarctic Surface Water. For example, most of the stock of *Euphausia superba* is confined to waters less than 2°C (Marr, 1962), while *E. crystallorophias* is restricted to waters of even lower temperature. The shrinking range of such key food species will compress dependent consumer species into a narrower band around Antarctica, increasing competition between predators. Around some sub-Antarctic islands, vital food resources may then be beyond the foraging range of adult seals and birds during the critical period of rearing the young. Croxal et al. (1987) showed that this already occurs sporadically at South Georgia.

One of the most far reaching effects of rising sea surface temperatures in the Southern Ocean would be a progressive reduction in the extent of sea ice, both in winter and summer. In an initial modelling of the potential impact upon Southern Ocean sea ice, Parkinson and Bindschadler (1984) concluded that a rise of 5°C in air temperature could result in the winter extent and volume of sea ice to be halved. As the increase in air temperature at high latitudes is anticipated to continue to rise well beyond that level, the winter extent of sea ice could be reduced even further.

Direct ecological impacts of a reduction in sea ice include loss of substrate for ice algae (an important component of primary production during winter and early spring), and less ice floes suitable for pupping and mating of ice seals (particularly crabeater and leopard seals) at the critical period during late October and early November each year.

One of the physical effects of a reduction in the extent of sea ice would be a loss of albedo and further absorption of solar energy into the surface of the Southern Ocean, accelerating the change in the energy balance.

An even more important feedback loop from a much reduced extent of winter sea ice would be a severe reduction in the pulse driving the vertical circulation of the waters of the Southern Ocean. With less sea ice formed, there would be less brine released to sink as Antarctic Bottom Water and hence diminution of the passage of dissolved CO_2 to be held in the deep ocean sink. With the weakening of the vertical circulation there would also be a decline in compensatory upwelling of nutrient rich water upon which phytoplankton and all higher consumers are totally dependent. A failure of phytoplankton blooms would represent a massive reduction in the fixation of CO_2 in Antarctic Surface Water, again feeding back to accelerate global warming.

A severe reduction in primary production within Antarctic Surface Water would have a disastrous impact on the Southern Ocean ecosystem as a whole, including the harvested species which CCAMLR is attempting to manage and conserve. Furthermore, a diminution of krill stocks through man-induced climate changes would severely retard (or reverse) the recovery of previously depleted populations of blue, fin and humpback whales, negating much of the hard-won ground by the IWC.

Further potential for impact upon the Southern Ocean ecosystem derives from the ultraviolet wavelengths penetrating the ozone hole now evident in the stratosphere over Antarctica each spring and early summer. Increasing penetration of UV band into the sea surface has potential to depress photosynthesis or even to be lethal to the more sensitive species in the phytoplankton, again depressing the productivity of the ecosystem as well as reducing the uptake of atmospheric CO_2. Precise field measurements are lacking, but Pittock et al. (1981) suggested that phytoplankton in surface waters would suffer appreciable mortality by a reduction of the ozone shield in the range of 16–30%. In October 1985 ozone levels over Antarctica declined by 50% (Ember et al., 1986). Concentrations of

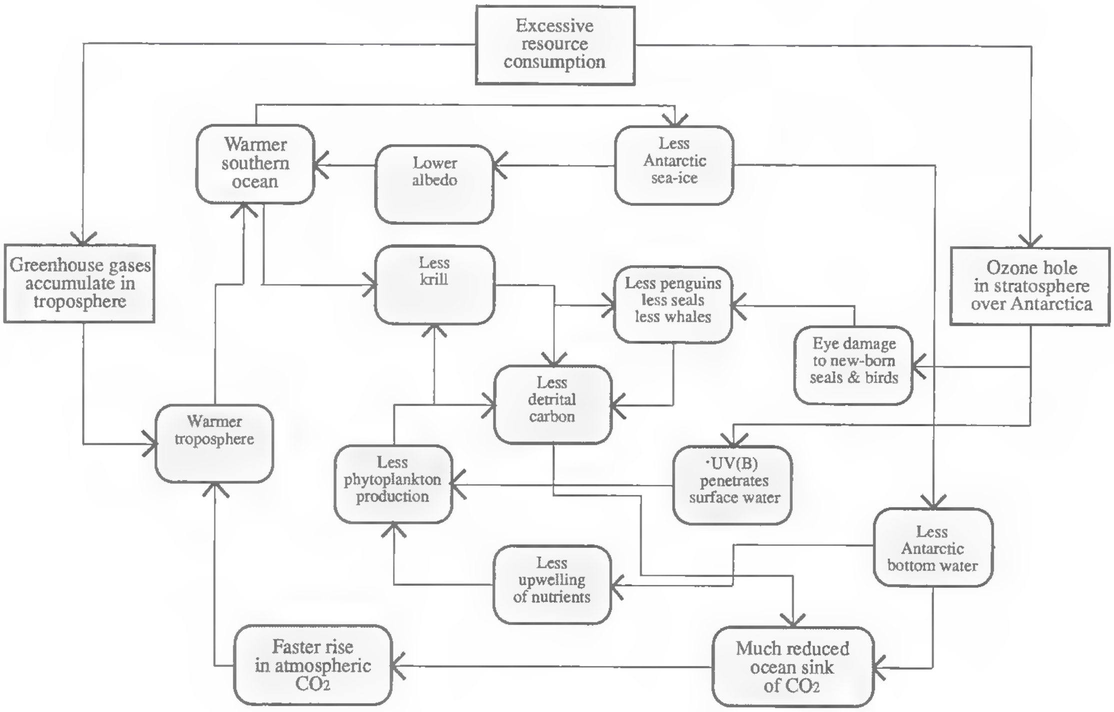

Fig. 2. Potential feedback loops within the Southern Ocean ecosystem resulting from climatic changes.

phytoplankton some tens of metres below the surface may be afforded some protection from UV radiation, but turbulent wind mixing bringing these organisms close to the sea surface may well make them more vulnerable.

Of more immediate impact could be the eye damage that the UV band might bring to new-born seals and birds. Particularly vulnerable here would be the pups of crabeater seals, born on ice floes in high latitudes late in October, close to the peak of the ozone hole. Again, direct measurements of sensitivity are lacking.

There are many potential feedback loops impacting on the Southern Ocean ecosystem from global warming and weakening of the ozone shield (Fig.2). Even if subsequent research finds that one or two of these processes are of relatively minor extent, the overall prognosis for the Southern Ocean ecosystem is extremely poor. Furthermore, the collapse of the important Southern Ocean CO_2 sink has global implications, greatly accelerating the rates of climate change that each of us will have to face.

It should be noted that other feedback systems in the Antarctic, not directly relating to the Southern Ocean ecosystem, but having potential to affect global climate change, are not discussed here. These include acceleration of break-up from the fringes of the Antarctic glacial ice sheet, and a weakening circulation of the Southern Ocean triggering a permanent ENSO phenomenon. As stressed by Thomas (1984) "we cannot rule out the possibility that a climate change of magnitude predicted for CO_2 doubling could radically alter ocean circulation". In particular, he points out that if the relatively warmer Circumpolar Deep Water is able to reach the major ice shelves without considerable cooling, ice shelves could thin enough for massively enhanced calving. "Clearly", he concluded, "we need to learn more about ocean behaviour near Antarctica."

CONCLUSION

There can be little doubt that the Southern Ocean ecosystem is threatened with severe and permanent collapse as a result of impending climatic changes. Such a collapse would halt the present recovery of humpback whale populations.

As scientists, we can design fascinating studies of the physical and biological impacts upon the Antarctic environment as global climatic changes progress. But do we not also have a wider responsibility to press for policy changes aimed at arresting the global processes before irreversible harm is done to the Antarctic environment and ecosystems? Although it is quite evident that we need far more research in this area, we can hardly afford to regard the Southern Ocean as a giant experimental unit if we are likely to lose control of the experiment.

Our role should be far more than the gathering of information. We would be failing in our social responsibilities if we do not make a clear statement on the urgent need for action to circumvent the setting up in the Southern Ocean of irreversible processes having high potential to cause massive environmental and ecological changes around Antarctica, as well as greatly accelerating changes in climate (and sea level) throughout the world.

Unless we act quickly and decisively, the conservation strategies presently being pursued by Australia within the IWC, CCAMLR and the Antarctic Treaty itself, become meaningless gestures. As stated recently by Dr Noel Brown of UNEP, the next decade is our last window of opportunity to make effective changes. Let's use that time to the full.

LITERATURE CITED

ALLISON, I.F. AND KEAGE, P.L. 1986. Recent changes in the glaciers of Heard Island. Polar Record 23 (144): 255–271.

BENTLEY, C.R. 1984. Some aspects of the cryosphere and its role in climatic change. Geophysical Monographs 29: 207–220.

BUDD, W.F. 1980. The importance of the polar regions for the atmospheric carbon dioxide concentrations, 115–128. In G.I. Pearman (ed.), 'Carbon Dioxide and climate.' (Australian Academy of Science: Canberra).

CHITTLEBOROUGH, R.G. 1984. Nature, extent and management of Antaractic living resources, 135–161. In S. Harris, ed., 'Australia's Antarctic Policy Options'. Centre for Resource and Environmental Studies. ANU Mon. 11: 135–161.

COMISO, J.C. AND GORDON, A.L. 1987. Recurring polynyas over the Cosmonaut Sea and Maud Rise. J. Geophys. Res. 92: 2819–2833.

CROXALL, J.P. et al. 1987. Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976–1987: implications for Southern Ocean monitoring studies. SC-CAMLR. Selected Scientific Papers 1987: 445–447.

EMBER, L.R. et al. 1986. Tending global commons. Chemical & Engineering News 64 (47): 14–64.

JACKA, T.H. 1983. A computer data base for Antarctic sea ice extent. ANARE Research Notes 13: 1–54.

JACKA, T.H., CHRISTOU, L. AND COOK, B.F. 1984. A data bank of mean monthly and annual surface temperatures for Antarctica, the Southern Ocean and South Pacific Ocean. ANARE Research Notes 22: 1–97.

MARR, J.W.S. 1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). Discovery Reports 32: 37–463.

PARKINSON, C.L. AND BINDSCHADLER, R.A. 1984. Response of Antarctic sea ice to uniform atmospheric increases. Geophysical Monographs 29: 254–264.

PITTOCK, A.B. et al. 1981. Human impact on the global atmosphere: impacts for Australia. Search 12: 260–272.

RIND, D 1984. Global climate in the 21st. Century. Ambio 13: 148–151.

SVERDRUP, H.V. et al. 1942. 'The oceans'. (Prentice hall: N.Y).

TAKAHASHI, T. 1987. Assessment of seasonal and geographic variability in CO2 sinks and sources in the ocean. In Reichle, D.E. et al., 'Environmental Sciences Div. Ann. Progr. Rep. for period ending Sept. 30 1986'. (Oak Ridge National Lab.: Tennessee).

THOMAS, R.H. 1984. Responses of the polar ice sheets to climatic warming. 301–316. In 'Glaciers, ice sheets and sea level: effects of a CO_2-induced climatic change. Report to U.S. Dept. of Energy. DoE/ER/60235-1.